TEXTILE FINE GRINED MORTAR CONTAINING PALM OIL FUEL ASH AS A PARTIAL CEMENT REPLACEMENT FOR FLEXURAL STRENGTHENING ON REINFORCED CONCRETE BEAMS

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ABSTRACT

Reinforced concrete (RC) beams represents a large percentage of the structure in buildings. As the beams structures known as bending elements, thus most of the structures are often exposed to bending loads, which can affect in serious deteriorations such as concrete cracking and spalling. Due to these factor, Textile Fine Grained Mortar with Palm Oil Fuel Ash (TFGM-POFA) as an upgrading strengthening method of concrete structure. Fine Grained Mortar inclusion POFA (FGM-POFA) with size 40 mm x 40 mm x 160 mm consist of fine sand less than 1 mm, ordinary Portland cement (OPC) and POFA as a partial OPC replacement. Flexural and compressive test was conducted to identify the optimum FGM-POFA. After that, the strengthening on concrete prisms derived from combination of optimum FGM-POFA and alkali resistant glass (ARG) to form TFGM-POFA with the minimum 2 mm of mortar thickness between the layers. The total numbers of 39 specimens of concrete prisms size of 100 mm x 100 mm x 500 mm were prepared with 2, 4, 6 and 8 layers of TFGM-POFA. This study also involves the different application of strengthening materials which are; mortar OPC and mortar OPC + ARG. Experimental works include three point bending tests on concrete prisms to determine the effect TFGM-POFA layer on concrete prisms. In addition to prism specimens, seven (7) RC beams with the size of 150 mm x 200 mm x 2500 mm were strengthened and tested with TFGM-POFA, mortar OPC and mortar OPC + ARG. The laboratory testing was conducted in four bending tests on RC beams. From the result, the optimum FGM-POFA was identified at 10 % of POFA replacement. The application of TFGM-POFA for all layers on concrete prisms is effectively enhancing the structures strength compared to the unstrengthened prism. The application of TFGM-POFA increased 36 % of the load carrying capacity of RC beams compared to unstrengthened RC beam. In conclusion, the best percentage is at 10 % of POFA replacement. The utilization of TFGM-POFA proven in increasing the flexural strength and significantly delaying the failure of concrete structure and TFGM-POFA 4 lead to a significant increase in the flexural load of RC beams

ABSTRAK

Rasuk konkrit bertetulang mempunyai peratusan terbesar dalam struktur bangunan. Oleh kerana struktur rasuk dikenali sebagai unsur lenturan, sebahagian besar struktur sering terdedah kepada beban lenturan yang boleh mengakibatkan kemerosotan rasuk yang serius seperti retakan dan serpihan konkrit. Oleh itu, *Textile Fine Grained Mortar* dengan kandungan abu kelapa sawit (POFA) atau dikenali TFGM-POFA merupakan salah satu kaedah pengukuhan struktur konkrit. Prisma *Fine grained mortar* dengan tambahan POFA (FGM-POFA) bersaiz 40 mm x 40 mm x 160 mm terdiri daripada pasir halus kurang dari 1 mm, simen (OPC) dan POFA sebagai pengganti simen. Ujian lenturan dan mampatan dijalankan untuk menentukan optimum FGM-POFA. Selepas itu, pengukuhan terhadap prisma konkrit juga dilakukan dengan gabungan optimum FGM-POFA dan gentian kaca than alkali (ARG) atau dikenali TFGM-POFA dengan ketebalan minimum 2 mm antara lapisan. Sejumlah 39 spesimen prisma bersaiz 100 mm x 100 mm x 500 mm disediakan dengan 2, 4, 6 dan 8 lapisan TFGM-POFA. Kajian ini juga melibatkan penggunaan bahan pengukuhan yang berbeza; mortar OPC dan mortar OPC + ARG. Ujian lenturan tiga titik dijalankan untuk menentukan kesan pelbagai lapisan TFGM-POFA pada prisma konkrit. Selain itu, tujuh (7) rasuk konkrit bertetulang bersaiz 150 mm x 200 mm x 2500 mm diperkukuhkan dan diuji dengan TFGM-POFA, mortar OPC dan mortar OPC + ARG. Ujian lenturan empat titik dijalankan pada rasuk konkrit bertetulang. Hasil kajian mendapati optimum FGM-POFA adalah pada 10 % penggantian POFA. Penggunaan TFGM-POFA untuk semua lapisan pada prisma konkrit juga berkesan meningkatkan kekuatan struktur berbanding prisma yang tidak diperkukuhkan. Pengukuhan TFGM-POFA terhadap rasuk konkrit bertetulang telah meningkatkan kapasiti membawa beban sebanyak 36 % berbanding rasuk yang tidak diperkukuhkan. Kesimpulannya, peratusan yang terbaik adalah pada 10 % penggantian POFA. Penggunaan TFGM-POFA terbukti dalam meningkatkan kekuatan lenturan dan melambatkan kegagalan struktur konkrit. TFGM-POFA-4 lapisan membawa peningkatan ketara dalam beban lenturan bagi konkrit bertetulang.

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R_f	Flexural strength, MPa
F_f	Total ultimate load, kN
b	Side of the prism, mm
l	Distance between support, mm
R_c	Compressive strength, MPa
F_c	Maximum load, kN
A	Area, m^2
Al_2O_3	Aluminium oxide
ARG	Alkali resistant glass
ASR	Alkali silica reaction
ASTM	American Society for Testing and Materials Standard
BS. EN	British Standard
CaO	Calcium oxide
CaOH	Calcium hydroxide
CMU	Concrete masonry units
CO_2	Carbon dioxide
C-S-H	Calcium silicates hydrates
CFRP	Carbon fibres reinforced polymer
FA	Fly ash
FGM-POFA	Fine Grained Mortar with Palm oil fuel ash
FRCM	Fibre Reinforced Mortar
FRPs	Fibre Reinforced Polymers
Fe_2O_3	Iron oxide
GFRP	Glass fibre reinforced polymer
GPOFA	Ground POFA
LOI	Loss of ignition

LS	Sodium lignosulfonate
LVDT	Linear variable differential transducers
NEG ARG	Nippon Electric Glass
NFS	Polynaphthalene sulfonate
OPC	Ordinary Portland cement
PSA	Particle size analyzer
POFA	Palm oil fuel ash
RC	Reinforced concrete
RHA	Rice husk ash
RMK-11	11^{th} Malaysia Plan
SEM	Scanning electron microscopy
SiO_2	Silicone dioxide
SF	Silica fume
SP	Superplasticizer
TFGM-POFA	Textile Fine Grained Mortar with Palm oil fuel ash
TIA	Timber industrial ash
TRC	Textile reinforced concrete
TRM	Textile reinforced mortar
US	Ultrafine silica
UPOFA	Ultrafine POFA
XRD	X-ray diffraction
XRF	X-ray fluorescence
ZrO_2	Zircon

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CHAPTER 1

INTRODUCTION

1.0 Introduction

The planning of the 11th Malaysia Plan (RMK-11) highlighted on the transformation of Malaysia in becoming as a developed nation by 2020. One of the objectives in this plan is a green growth with environmental sustainability. In this objective, it focuses on adopting the sustainable consumption and strengthening the existing environment for green growth. Sustainable consumption is a waste from the resources that can be reused through recycling and recovery (Economic Planning, 2015). Thus, one of the steps that can be made by utilizing the waste materials such as palm oil fuel ash (POFA), rice husk ash (RHA), bagasse ash and timber industrial ash (TIA) in construction industry.

In construction industry, it is normal to face buildings that have reached the end of their service life and experienced deterioration due to some reasons such as concrete cracking and spalling (Usman and Resdiansyah, 2015; Negrutiu *et al.*, 2016). Due to these factors, strengthening system should be developed. Strengthening may be defined as an intervention to increase the original strength and stiffness of the building element. The strengthening process also can be proceeded with repair operation (Julio *et al.*, 2003). Therefore, the challenge that might be faced is to implement the effective and economical system of strengthening.

In this study, the structure element was focused on beam. Generally beam is a horizontal structure member that is used to carry transverse load. It is a major component of building structures. It should be designed to be able to withstand the subjected loads primarily by resisting against bending (Djamaluddin, 2013). For the structures that are suffering from various causes of deteriorations may attributes to cracks, large deflections and others. To reduce the deteriorations of reinforced concrete (RC) beams, several methods of strengthening should be considered (Orosz *et al.*, 2007; Elsanadedy *et al.*, 2013; Babaeidarabad *et al.*, 2014; Rashidi and Takhtfiroozeh, 2016).

However, there are still lack in utilization of pozzolanic materials in their studies. Thus, in support of RMK-11 plan, this study was using POFA as a cement replacement material in mortar binder for strengthening of RC beams.

1.1 Background of study

Mortar is functioning as provider for stability and durability to masonry structures such as brick, block or other in the complete bonding. It accommodates movement of the structure, provides rapid development of strength and adequate strength when hardened, resistant to the action of environmental factors such as frost or abrasion, destructive effects of chemical salts such as sulphate attack, resists the penetration of rain in the building structure and give an aesthetic appearance (Mortar Industry Association, 2013). Hence, due to the benefits of the mortar along with some improvement, it may also contributes in strengthening other structure elements. The application of mortar may become an effort to improve the strength of the beam to the safety state.

This study focusing on the applications of new innovation of mortar binder composite for flexural strengthening of reinforced concrete (RC) beams. The mortar binder used in this study has a mix design with the maximum size of fine grained sand used is 1 mm. Mortar with a new mix design is namely Fine Grained Mortar (FGM). In this study, FGM is being used with waste pozzolanic material which is POFA as cement replacement and known as FGM-POFA. By the addition of some pozzolanic materials such as POFA, it is expected to improve the properties of mortar for instance workability, strength, durability, resistance to cracks and another characteristic of mortar (Usman *et al.*, 2015).

On the other hand, some researchers (Brückner *et al.*, 2006; Blanksvärd, 2008; Hinzen and Brameshuber, 2009; Si Larbi *et al.*, 2013) have recognized that textile fibres could enhance the properties of concrete too. Blanksvärd *et al.* (2008)

reported that the use of carbon fibre reinforced polymers (FRPs) provides the highest strengthening effect and that the fibres should be imbedded into a matrix to enhance utilization of inherent strain capacity. The study conducted by Hinzen and Brameshuber (2009) identified that the first crack stress could be improved by about 40 % when textile fibre has been employed. Other than that, alkali resistant glass (ARG) is specifically used in concrete or mortar due to the high elastic modulus (Harle, 2014). Also, the use of ARG fibres in concrete increase the strength and stiffness of fibres in reinforcing the brittle matrix (Desai *et al.*, 2003). Thus, in this study ARG has been opted as a textile fibre for increasing the strength.

For generating an effective method of beam strengthening, a new mixture has been identified. This new mixture is called as Textile Fine Grained Mortar (TFGM). TFGM-POFA is the combination between FGM, POFA and ARG. TFGM-POFA is a tremendous mixture for increasing the strength of RC beam.

1.2 Problem statement

Technically, buildings have a finite service life. For building that is exposed to harsh environments, they may experience significant deterioration. Buildings are designed to withstand loads imposed to them during their service. With a proper planning, the building could serve as it was proposed (Usman and Resdiansyah, 2015). To produce a quality building, selection of good materials is important. The strength of the material is essential in producing strong structure elements. This situation is similar when referring to the structural strengthening. The process of reconstruction, renewal, upgrading the structural system of an existing building to improve performance under existing loads or to increase the strength of structural components to carry additional loads are required for strengthening of the structures.

RC beams represents a large percentage of structure in buildings. As the beams structures known as bending elements, thus most of the structures are often exposed to bending loads, which can affect in serious deteriorations. In term of structural stiffness, the structures element must be effective to resist bending. In bending part, the composite failure occurs on either the tensile or compressive side depending upon whether the composite is stronger in compression or tension respectively (Rathnakar and Shivanand, 2012). Due to these factor, the improvement in strengthening system can be develop as an upgrading strengthening method of concrete structure.

Based on Blanksvärd *et al.* (2008), there were various methods proposed to strengthen the concrete structure, one such commonly used was FRP bond with epoxy. It is the most popular technique for the strengthening of RC beams. However, the limitations of the epoxy were a lack of vapour permeability, low reversibility, poor fire resistance and poor behaviour of resin under a certain temperature. Other than that, this type of epoxy resin suffers from emits toxic organic gas during the manufacturing process as stated by Si Larbi *et al.* (2013). Therefore, the other way to replace the epoxy as a binder is using mortar because mortar also can be categorized as a binder agent.

Generally, mortar is used to bond masonry unit into the appearances structural element, provides rapid development of strength and adequate strength when hardened as aforementioned before. However, in the situation of wind load or high lateral strength, the common mortar does not support this case and mortar with the high flexural bond strength should be considered (Brick Industry Association, 1991). The mortar can be improved with the addition of suitable waste materials as the hardening cementitious mortar for externally strengthening system. The high performance of the mortar binder can be achieved significantly through the utilization of textile fibres and pozzolanic materials that will enhance the mechanical properties of concrete. Hence, the application of textile fibres with hardening cementitious mortar could be one of the improvement in strengthening method.

In addition, the production of cement created a problem due to the release of carbon dioxide (CO_2) during the production that can harm the environment. Huntzinger and Eatmon (2009) discovered that the carbon emission increased the global warming. To ensure the environment sustainability, one such method is the utilization of waste materials as a cement replacement in a mortar binder to enhance the strength. The application of waste materials such as fly ash (FA) has long been in practice by previous researcher and became significant in the concrete industry, however these materials are decreasing in the years to come (Nguong and Abdul Awal, 2010). Therefore, the pozzolanic material like POFA could enhance the strength and reduced the usage of cement. POFA is a waste that has the potential to be used as a partial replacement of cement because it also has pozzolanic features that are cementing property (Awal and Hussin, 1997). In this study, the hardening cementitious mortar, FGM-POFA was introduced as an alternative binder for the strengthening of RC beams. The improvement was made in a strengthening by mortar binder which is FGM-POFA with 600 µm up to 1 mm maximum grade size of fine sand and POFA as OPC replacement.

The investigation by Rashidi and Takhtfiroozeh (2016) expressed that other method to strengthen the RC beams was to be wrapped with fibres reinforced polymers (FRP) sheets. It has a significant impact on increasing the ductility of RC beam. Nevertheless, the wrapping is not possible with FRP as a method system due to the rigidness and brittleness (Blanksvärd, 2008). Another alternative is Carbon fibres reinforced polymer (CFRP) laminate was fabricated natural fibre based on jute rope composite plate. According to a study by Nouri (2016), a beam that was strengthened with jute rope composite plate had less deflection under the high load but it weakness was found in ductility since it was almost the same with unstrengthen beam. Textile fibres from steel plates and FRP were the popular strengthening materials compared to the ARG, but both FRP and steel plate materials were still lacking as aforementioned. Hence, the replacement of FRP with ARG could give the high elastic modulus thus improve the strength of RC beam. Other than that, ARG had a larger load carrying capacity than plate specimen due to coupled effect of the orientation of cross-section and the direction of fabric (Zhu *et al.*, 2009).

In this study, the application of FGM-POFA was not only well accepted as building materials. Therefore, it suggested that with additional of textile fibres it became a tool to improve the flexural strength of RC beams (D'Ambrisi and Focacci, 2011; Elsanadedy *et al.*, 2013; Babaeidarabad *et al.*, 2014). The utilization of textile fibres from ARG types added more benefits in enhancing the strength and ductility of RC beams. Thus, the combination of FGM-POFA with ARG is called Textile Fine Grained Mortar inclusion POFA (TFGM-POFA).

1.3 Research objectives

The main purpose of this study is to achieve the following objectives:

1) To identify the optimum mix design of FGM containing POFA as a partial cement replacement.
2) To investigate the effects of TFGM-POFA in various layers for strengthening of concrete prism.

3) To determine the strengthened reinforced concrete beams with TFGM-POFA for flexural strengthening.

1.4 Scope of study

The study was conducted in the three major phases. The first phase is development of optimum mix design of FGM-POFA. In this phase, 108 nos of FGM-POFA prisms with a size of 40 mm x 40 mm x 160 mm was made. FGM-POFA consist of binder materials (cement + POFA), fine sand with maximum grain size 1 mm, superplasticizer and water. POFA as a cement replacement material was ground and sieved using on sieve No. 325 (45 µm) with 1 % to 3 % of retained as natural pozzolans (ASTM C618, 2005). Cement was partially replaced with POFA at 0 %, 10 %, 20 %, 30 % and 40 % by weight of cementitious materials. The mixture composition of mortar content, cement and sand were designed according to the BS EN 196-1 (2005). The prism specimens were tested by flexural and compressive testing at the age of 7, 28 and 90 days by using BS EN 196-1 (2005).

Other than that, the second phase consist of development of TFGM-POFA on concrete prisms with externally strengthened. In this phase, 39 nos of concrete prism specimens with a size of 100 mm x 100 mm x 500 mm was produced. The optimum mixtures of FGM-POFA was combined with textile fibre (ARG) to develop the TFGM-POFA. Then, TFGM-POFA was strengthened on concrete prisms with 2, 4, 6 and 8 layers. The unstrengthen concrete prisms also included as a control specimens. All the specimens were tested for the flexural strengthening.

The third phase is applying TFGM-POFA on RC beams for the flexural behaviour of strengthening. Total of seven (7) nos of RC beams with size 150 mm x 200 mm x 2500 mm was designed based on BS EN 1992: Eurocode 2 (2011) and strengthened with TFGM-POFA made of optimum proportioning. It was tested for the flexural strengthening. The compressive strength of concrete for RC beams was determined from six of 150 mm cubes during the casting of beams in order to evaluate the toughness of grade concrete.

1.5 Research framework

This topic presents the research framework of this study. The details explanation on research methodology is discussed in Chapter 3. There were 3 phases was developed to identify the research objectives and effectiveness of TFGM with POFA, as shown in Figure 1.1.

In this study, the Phase 1 described the characterization of raw material that were utilised in FGM-POFA which were POFA, fine sand and others. Then, the FGM-POFA was developed to identify the optimum mix design of FGM-POFA. Meanwhile, the Phase 2 consisted the formation of TFGM-POFA which is combination of FGM-POFA and ARG fibres. This phase also investigates the effect of TFGM-POFA layers number on concrete prisms. Lastly, Phase 3 was the application of TFGM-POFA for strengthening the RC beams. This phase determined the strength of RC beams by flexural strengthening after strengthened with TFGM-POFA.

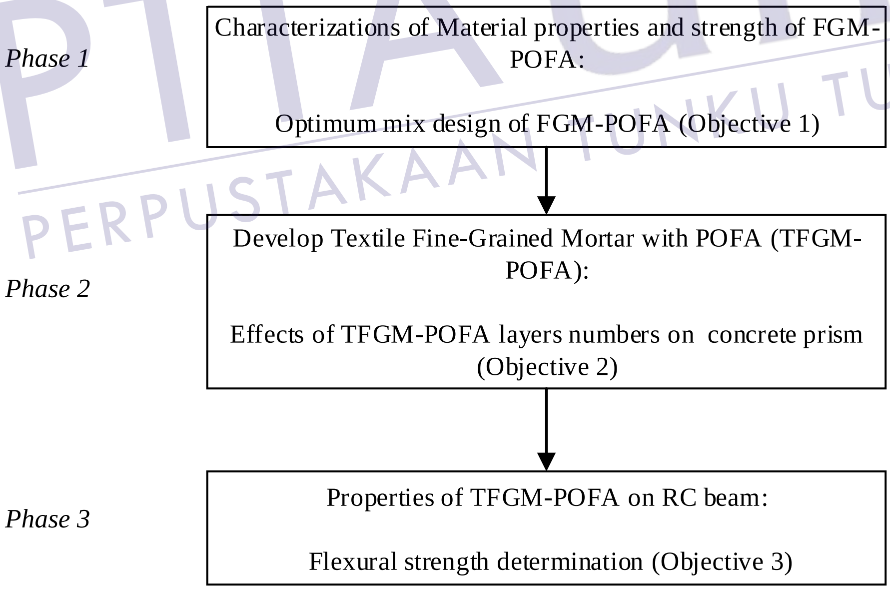

Figure 1.1: Research framework

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